Thesis/
Reports
Gosz,
J. R.

IMPACTS OF TRAMPLING ON UNDERSTORY VEGETATION AND WATER QUALITY IN ASPEN AND CONIFER STANDS

Final Report

for

Eisenhower Consortium Study (EC 365)

Grant RM-80-114-GR

by James Gosz

"Impacts of trampling on understory vegetation and water quality in aspen and conifer stands"

INTRODUCTION

Although the use of aspen for recreational areas may provide certain benefits (e.g. aesthetics, ease of regeneration, low fire risk), there are a number of characteristics of this vegetation type which, under recreational pressure, could lead to adverse water quality. The forest floor of an aspen stand is relatively thin because of the rapid decomposition of its litter (Gosz 1980). Since the forest floor is important in intercepting precipitation and preventing erosion, recreational pressure may cause more adverse effects in aspen than in conifer areas. The herbaceous understory is very productive in aspen stands and not only is important in protecting the soil from erosion but also cycles a large proportion of the nutrient capital; both are important factors in maintaining good water quality. The trampling of recreationists may seriously affect the productivity and nutrient uptake capability of this layer. The soil of aspen stands is more nutrient rich than that of conifers and nitrification ($NH_4^+ \rightarrow NO_3^-$) is an important process (Gosz 1978). In soils with high nitrification rates, distrubance often causes significant losses of NO_3^- and other nutrients (Vitousek et al. 1979). The ease with which the understory and litter layer can be disturbed, the high nitrification rates, and increased water reaching the soil (less interception) may cause larger

LIBRARY COPY
ROCKY MT. FOREST & RANGE
EXPERIMENT STATION

changes in water quality in aspen than in conifer stands following recreational pressure.

Silvicultural management is necessary to maintain productive, healthy aspen stands. However, this more intense management activity may cause large and/or frequent water quality changes (Vitousek et al. 1979). Since a very important recreational effect is simply the "trampling effect" of people, the specific objective of this study was to quantify the relationship between the trampling effect of recreationists, vegetation disturbance, soil disturbance, and water quality for conifer stands as well as aspen stands under different management procedures. To establish this relationship:

1. Different trampling intensities were established in a natural conifer stand, a natural aspen stand, a thinned aspen stand, and a fertilized aspen stand.

2. The effect of trampling was measured on understory vegetation diversity and biomass, forest floor mass, forest floor nutrient content, soil density and permeability, and soil leachate chemistry.

SITE DESCRIPTION

The study sites are located in the Tesuque Watershed Study Area, Sangre de Cristo Mountains, New Mexico. The general vegetation, geology, topography, and climatic factors of the area were described by Gosz (1975, 1978, 1980). The aspen study site is at 3150m elevation on a south facing aspect. The soil is a Typic Cryocrept (Medio cobbly loam) which was developed from parent materials derived from the Embudo granite formation. More detailed soil information is available in Gosz (1980).

The sites selected for the natural, thinned, and fertilized aspen stands are very close to each other and within the same watershed. The

thinning was performed in 1975. It consisted of a 25% stem reduction (every 4th stem was felled regardless of size). The fertilized stand is located within 50m of the thinned area and 20m downslope of the natural stand. Fertilizer (urea) was applied in 1979 at a rate of 609 kg/ha (Grover, unpubl). The uniform nature of the aspen (resulting from an 1886 burn), soil, and topography reduce the likelihood of a significant site or site x treatment interaction factor.

The conifer forest is a spruce-fir forest at 3350m elevation. It is on a west aspect and the soil is a Dystric Cryocrept (Nambe cobbly loam) derived from the Embudo granite formation.

METHODS

A major factor in our research plan is that a number of management practices (i.e. thinning, fertilizing) have already been performed in our study area and are being evaluated. The "trampling" effect was added and was evaluated immediately.

At each of the four sites (i.e. natural aspen, thinned aspen, fertilized aspen, natural spruce-fir), three contiguous 10m x 10m plots were established with permanent plot markers. One plot served as a control, one for low intensity trampling and one for high intensity trampling. Low intensity trampling was defined as three walking passes/week (i.e. the entire 10m x 10m plot was walked over three times/week). High intensity trampling was 18 walking passes/week. The trampling treatments were applied weekly throughout the study period of June 1 to Sept. 1, 1980.

Figure 1 shows the layout of the three 10m x 10m plots of each site as well as the location of the individual $1/2m^2$ sampling subplots for var-

ious measurements. The 1 m wide strips between subplots and plots allowed access for measurements of the following parameters:

Forest Floor Biomass. Initial (June 1) and final (Sept. 1) forest floor biomass was measured by the use of $100cm^2$ templates as described by Gosz et al. (1976). Ten replicates were taken from each 10m x 10m plot at each sampling time. These samples were taken randomly from the $1/2m^2$ subplots. The forest floor samples were analyzed for total N, total P, Ca, Mg, K, and ash content.

Forest Floor Extractable N. At monthly intervals, 10 samples of each the forest floor and 0-10 cm depth soil were collected (with a soil corer) from each plot to monitor: a) KCL extractable NO_3^- and NH_4^+. This estimates rates of N mineralization; b) organic matter content; and c) moisture content. These samples were taken randomly from the $1/2m^2$ subplots.

Herbaceous Biomass. Final above-ground, herbaceous biomass was evaluated on Sept. 1 by clipping five $1/2m^2$ subplots on each of the 10m x 10m plots. These were chosen randomly from the subplots. The herbaceous plants were separated into three groups: grass, legumes, and other forbs.

Soil Bulk Density. Initial (June 1) and final (Sept. 1) bulk density was measured by determining the oven-dry weight of the soil extracted with a 10 cm soil corer to a depth of 10 cm. The volume of the sample was determined by measuring the volume of water required to fill a plastic bag placed in the sampling hole. Five measurements were made at each sampling time from subplots chosen at random.

Soil Solution Chemistry. Porous cup tension lysimeters were installed (1/2m deep) beneath each of the permanent plots to allow sampling of the soil solution. They were installed at an angle (entering from the edge of

the plot) to allow routine trampling and vegetation measurements. The ten replicate lysimeters of each plot were sampled biweekly when possible and the sample analyzed for NO_3^- to determine the potential for loss in drainage water.

Herbaceous Vegetation Measurements. Ten $1/2m^2$ herbaceous plots were chosen randomly and sampled monthly in each 10m x 10m plot using a vertical point frame (36 points per $1/2m^2$ plot). No other surface sampling procedures were performed on these subplots. Data collected using this procedure were expressed as;

species % foliage cover:

$$\frac{\text{number of times a species is hit}}{\text{number of readings (rods)}} \times 100$$

note - a species is recorded only once/rod

relative % cover:

$$\frac{\text{\% cover of a species x (100-bareground)}}{\text{total \% cover/number of readings}} \times 100$$

litter and down log cover/bare ground.

relative frequency:

$$\frac{\text{frequency of a species}}{\text{total number of vegetative hits}} \times 100$$

Soil Permeability. Initial (June 1) and final (Sept. 1) soil permeability was measured using a single ring infiltrometer (galvanized steel pipe, 21.5 cm dia., driven approximately 2 inches into the soil profile). Five measurements were made in each treatment plot by timing the disappearance of 1000 mls of water from the infiltrometer in each of the randomly chosen subplots. These data were expressed as $mls/cm^2/sec$.

Chemical Procedures. Forest floor biomass samples were analyzed for total-nitrogen (TN), total phosphorus (TP), Ca, Mg, and K. Total nitrogen and TP analyses were performed using a Technicon Auto Analyzer following wet digestion of forest floor samples using concentrated H_2SO_4, 30% H_2O_2,

and K_2SO_4:$CuSO_4$ catalyst with heating until clear (Schuman et al. 1973). Sample preparation for cation analyses using a Perkin Elmer model 306 Atomic Absorption Spectrophotometer required ashing a subsample of forest floor material (500°C for 2 hrs.), then solubilizing the ashed sample in 6N HCl with heating.

Soluble and exchangeable forest-floor NH_4^+ and NO_3^- were determined using KCl extraction procedures. While in the field, 2 g subsamples of forest-floor material, or 6 g subsamples of soil (approximate weights) were added to polyethylene bottles containing 100 mls of 2N KCl with PMA (phenyl mercuric acetate) added to suppress biological activity. Simultaneously, equal weights of samples were placed in soil cans for moisture content and organic matter content. Exact sample weights were determined by weighing KCl bottles before and after sample collection. Approximately 24 hours after collection, a sufficient volume of sample + KCl solution was decanted and centrifuged to obtain a clear supernatant for direct NH_4^+ and NO_3^- analyses on the Technicon Auto Analyzer. Organic matter content of forest-floor biomass and monthly forest floor and soil collections was determined by ashing 1 g subsamples at 500° for 2 hours.

Soil solution samples were analyzed directly for NO_3^- using the Technicon Auto Analyzer. PMA was added to these samples in the field to suppress biological conversion of sample nitrogen forms before analysis.

RESULTS

Herbaceous Vegetation

The understory of the aspen stand responded markedly to the different management treatments as well as trampling pressures. Although the total herbaceous biomass did not vary significantly between the untrampled

natural, thinned, and fertilized aspen stands, the relationship between grasses, legumes, and other forbs varied markedly. The natural aspen stand had an understory dominated by legumes (Vicia americana, Lathyrus arizonicus) while the thinned stand was dominated by other non-leguminous forbs and the fertilized stand was dominated by grasses (fig. 2). Heavy trampling (18 walking passes/week) caused highly significant reductions in understory biomass ($p < .01$) with the dominant groups showing the greatest reductions (fig. 2). The heavy trampling caused a much greater reduction in the natural and fertilized stands than in the thinned stand. This was in spite of the fact that the fertilized stand was dominated by grasses which have been reported to be more resistant to trampling (Burden and Randerson 1972).

The light trampling also caused a significant reduction ($p < .05$) in understory biomass for the natural and fertilized stands; again primarily in the dominant plant group (fig. 2). The reduction in the thinned stand was not statistically significant ($p > .05$).

The conifer forest (spruce-fir) had a small understory component of non-leguminous forbs (table 1). Heavy trampling significantly reduced this component ($p < .01$) while the reduction caused by light trampling was not significant ($p > .05$).

The influence of the trampling through the season is shown well by relative coverage and frequency data (fig. 3,4, table 2,3). The heavy trampling treatment caused a near linear reduction over time in the relative cover of all plant groups (legumes, grasses, non-legumes) for natural, fertilized, and thinned aspen stands. The untrampled plots showed either no change in relative

coverage (fertilized and natural) or a significant increase ($p < .05$, thinned) during the summer months. This is due to the difference in dominant groups on the three sites and the phenological differences for those groups. The dominant grasses and legumes of the fertilized and natural stands emerged early and by June had attained a high relative cover. The thinned stand, dominated by non-leguminous forbs, showed a continuous increase in relative coverage through the summer.

The relative coverage of understory plants (non-legumes) for spruce-fir was low. The heavy trampling caused a reduction in relative coverage while the untrampled plot showed a general increase in relative cover like that of the thinned aspen stand.

Forest Floor

Forest floor weight measurements made for the three plots of each stand in May (before trampling) showed no significant differences ($p > .05$, table 4). This again reaffirms our faith in the uniform nature within each stand. There were significant differences between the three aspen stands ($p < .05$); a result of the thinning and fertilization procedures. The forest floor weight of the spruce-fir stand was greater than any of the aspen stands which was expected.

The late August collections showed several patterns depending on stand and trampling intensity. The untrampled plots for thinned and fertilized aspen and spruce-fir stands showed non-significant differences between May and August collections. The untrampled plot for the natural aspen stand showed a significant increase in the August collection (by both t - test ($p < .05$) and Mann-Whitney ($p = .05$)). The reason for this increase is not known. We expected a decrease because of decomposition during the warm summer months. The other stands showed a decrease although not significant (table 4). An increase in the forest floor weight could be caused by litter from the understory but the increase of about 2600 g/m^2 is too great to be explained by that process.

Heavy trampling during the summer caused significant ($p < .05$) reductions in the forest floor of the fertilized and thinned aspen stands. The reductions in the heavily trampled natural aspen and spruce-fir stands were not significant ($p > .05$). The light trampling caused significant reductions in forest floor weight only in the fertilized aspen and spruce-fir stands.

Regardless of change in weight in the forest floor of trampled aspen plots, the condition of the forest floor was altered greatly. The litter

material was highly fragmented, almost in a powder form. The summer months of 1980 were relatively dry resulting in minimum erosion. We would expect this fragmented material to be very easily moved by raindrop impaction and surface runoff. In contrast the forest floor of the spruce-fir forest appeared unaltered even after heavy trampling. The rather spongy character of the forest floor and rigid nature of the conifer needles appear to absorb trampling pressure very well. The August collections from trampled and control plots of the spruce-fir stand were not significantly different ($p > .05$).

In addition to a reduction in the forest floor of some stands, trampling caused some redistribution and the appearance of bare ground (table 5). Heavy trampling did not cause significantly more % coverage in bare ground than light trampling ($p > .05$) but the two trampling intensities caused significantly ($p < .05$) more bare ground exposure than the un-trampled control for the natural and thinned aspen stands. The fertilized aspen stand had much more bare ground as a result of higher rodent (mole) activity causing non-significant ($p > .05$) differences between trampled and control plots. This influence of fertilization on rodent activity is very interesting, has not been acknowledged often, and deserves more work.

The influence of trampling on the nutrient content of the forest floor paralleled patterns of forest floor weight in most cases (table 6). This means concentrations of nutrients were not altered markedly. In only one instance did N and P increase markedly in concentration while forest floor weight decreased (i.e. heavily trampled and fertilized aspen plot). That increase was only significant at the 10% level, however.

Soil

An anticipated result of trampling was an increase in soil bulk density and a decrease in permeability to water. The data show weak trends in that direction but the variability was so large that only several differences were significant ($p < .05$). Heavy trampling resulted in a significant decrease in permeability in the natural aspen stand and both heavy and light trampling increased bulk density significantly in the fertilized aspen stand (table 7). Improved methods and/or increased sample size are needed to verify the other trends.

An important consequence of trampling may be altered nitrification rates and leaching of nitrate to the ground water. The summer of 1980 was exceptionally dry resulting in few collections of soil water by lysimeters. Lysimeters were first collected for aspen stands in early August but by that time the soils were sufficiently dry so that only about one-half of the lysimeters sampled soil moisture (table 8). In September and October only one-tenth of the lysimeters were able to sample soil moisture. The lack of data prevents meaningful tests on the leaching of nitrate to ground water at this time. There are several trends, however, that indicate this process may be important during wetter conditions. For thinned and natural aspen stands on Aug. 2, the order of nitrate concentrations in soil moisture was heavy trampling > light trampling > control. Only in the natural aspen stand were those differences significant ($p < .05$). The fertilized stand had very high and variable nitrate levels in all of the treatment plots. Another pattern was apparent in the number of lysimeters which collected samples. By early August lysimeters in the natural aspen stand collected samples only from the trampled plots. In September and October

all of the aspen stands showed this pattern and in addition the majority of samples came from heavily trampled plots. This data evidences the role of the understory in transpiring soil moisture and reducing soil leaching. Trampling reduces this transpiring surface.

Although the spruce-fir stand is in a moister environment only about one-half of the lysimeters collected soil moisture during the late August to October period. Nitrate concentrations were very low or non-detectable for these samples and there was no measureable difference between trampled and control plots.

The litter and soil also were sampled and analyzed for extractable ammonium and nitrate. These measurements could still identify an influence of trampling on the rate of nitrification and buildup of nitrate in the soil which could be leached to ground water with the advent of moist conditions.

There was a pattern of nitrate accumulation in litter and soil across all of the aspen stands. Concentrations rose to a maximum during June and early July and fell rapidly in August. Ammonium concentrations remained low or fell in June and July, then increased significantly in August. These patterns also were reported by Gosz (1978) and are believed to result from the warm, dry, oxidative conditions in the forest floor in June followed by cooler (cloudy), and more moist conditions in July and August. The nitrate decrease in late summer may be due to plant uptake and/or denitrification (fig. 5,6,7).

Heavy trampling caused higher nitrate concentrations in litter in all three aspen stands; however, the differences were not significant because of high variability. There were no significant differences among treatments in ammonium concentrations. The fertilized aspen stand again demonstrated the highest overall nitrate levels. In soil the heavy trampling caused somewhat higher nitrate levels in August although the differences were nonsignificant due to high variances (fig. 8). A higher nitrate level late in the summer in trampled plots may be the result of reduced uptake by plants and/or less denitrification.

SUMMARY

As expected, heavy trampling caused marked effects on understory, litter, and soil properties. Any strategy which reduced this recreational pressure can be expected to reduce the impact on these forest systems. Of greater value is the knowledge that different management activities also influence the effects of trampling. This influence is the result of changes in the forest floor and understory composition under different management. Our results demonstrate that, in aspen, a 25% thinning was most effective. It resulted in an understory primarily of non-leguminous forbe which continued to increase in % cover throughout the summer months. The other stands had understories which peaked early in the summer and appeared less able to recover (by growing) after trampling. The literature suggests a grass understory is the most resistant to trampling. Our data suggests an understory which is better able to grow after a disturbance is more effective. This can be accomplished by thinning which allows more light to reach the understory. Our research shows that we can increase the grass component by fertilizing and an obvious management option to test would be a combination of fertilizing and thinning. Fertilization has other disadvantages, however. The very high nitrate levels in the forest floor, soil and soil moisture in fertilized stands can contribute to altered stream water quality.

The most resistant stand was the spruce-fir stand. The larger accumulation of needle litter and sparse understory are prime factors in the lack of an effect due to trampling. The rigid, tough nature of needle litter not only resists breakage and disruption but absorbs the physical impact of trampling preventing soil disturbance. One of the most successful ways of reducing the effects of recreational pressure may be that of encouraging or establishing conifer vegetation. Confining recreational areas to coniferous habatits should also be effective.

LITERATURE CITED

Burden, R.F. and P.F. Randerson. 1972. Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. J. Appl. Ecol. 9:439-457

Gosz, J.R. 1975. Nutrient budgets for undisturbed ecosystems along an elevational gradient in New Mexico. pp. 780-799 in (F.G. Howell, J.G. Gentry, and M.H. Smith, eds.) Mineral Cycling in Southeastern Ecosystems. Energy Research and Development Agency Symposium Series CONF-740513. Springfield, Virginia. 898pp.

Gosz, J.R., G.E. Likens, and F.H. Bormann. 1976. Organic matter and nutrient dynamics of the forest and forest floor in the Hubbard Brook Forest. Oecologia 22:305-320.

Gosz, J.R. 1978. Nitrogen inputs to stream water from forests along an elevational gradient in New Mexico. Water Research 12: 725-734.

Gosz, J.R. 1980. Biomass distribution and production budget for a nonaggrading forest ecosystem. Ecology 61:507-514.

Schuman, G.E., M.A. Stanley, and D. Knudsen. 1973. Automated total nitrogen analysis of soil and plant samples. Soil Sci. Soc. Amer. Proc. 37:480-481.

Vitousek, P.M., J.R. Gosz, C.C. Grier, J.M. Melillo, W.A. Reiners, and R.L. Todd. 1979. Nitrate losses from disturbed ecosystems. Science 204: 469-474.

Table 1. Mean (standard error of $\bar{x}$) understory biomass in natural, fertilized, and thinned aspen stands and a spruce-fir stand. Values are g m^{-2}. Heavy (H), light (L), and control (C) plots identify trampling intensities.

ASPEN STAND

NATURAL	LEGUMES	NON-LEGUMES	GRASSES	TOTAL
H	5.2(2.31)	2.7(1.14)	0.9(0.38)	8.8(2.18)
L	28.2(3.00)	3.1(1.72)	3.0(1.00)	34.2(4.89)
C	47.9(9.65)	2.0(0.59)	1.4(1.22)	56.8(11.88)
FERTILIZED				
H	5.4(2.36)	1.5(1.15)	4.7(1.21)	11.6(2.17)
L	5.7(1.36)	6.9(1.96)	15.5(2.33)	28.1(3.99)
C	14.9(2.77)	11.3(2.37)	16.4(3.04)	42.5(4.58)
THINNED				
H	4.9(2.00)	17.2(4.33)	4.2(1.21)	26.3(6.74)
L	3.7(1.34)	33.8(5.69)	9.8(3.05)	47.3(6.60)
C	9.0(3.64)	38.8(4.52)	11.5(2.26)	59.2(4.42)
SPRUCE-FIR STAND				
H	0.0	1.3(0.58)	0.0	1.3(0.58)
L	0.0	6.5(2.31)	0.0	6.5(2.31)
C	0.0	9.8(3.35)	0.0	9.8(3.35)

Table 2. Relative % cover over time of understory plant groups in aspen stands subject to different trampling intensities.

		STAND								
		ASPEN FERTILIZED			ASPEN NATURAL			ASPEN THINNED		
TRAMPLING INTENSITY		HEAVY	LIGHT	CONTROL	HEAVY	LIGHT	CONTROL	HEAVY	LIGHT	CONTROL
DATE	VEGETATION									
5/28/80	LEGUME	0.0	0.0	0.0	0.6	0.8	1.7	0.3	0.0	0.0
	NON-LEGUME	0.6	0.3	0.5	0.0	0.0	0.0	0.8	1.4	1.1
	GRASS	0.8	3.6	4.0	1.1	0.3	0.0	0.3	0.6	1.1
	TOTAL	1.4	3.9	4.5	1.7	1.1	1.7	1.4	2.0	2.2
6/24/80	LEGUME	19.8	17.8	20.9	38.9	63.1	71.4	17.2	15.2	9.3
	NON-LEGUME	4.0	13.6	12.4	2.6	2.8	7.1	10.4	14.5	28.3
	GRASS	8.0	14.2	12.9	2.9	2.8	2.0	2.4	3.9	2.3
	TOTAL	31.9	45.6	46.2	44.4	68.7	80.5	30.0	33.6	39.9
7/23/80	LEGUME	10.3	12.9	18.8	20.2	53.8	70.4	12.0	15.6	9.1
	NON-LEGUME	2.5	10.4	12.4	2.9	3.6	9.3	9.8	3.3	35.5
	GRASS	5.0	11.9	11.0	0.8	2.8	3.4	2.6	5.8	5.7
	TOTAL	17.8	35.2	42.2	23.9	60.2	83.1	24.4	44.7	50.3
8/20/80	LEGUME	3.8	10.1	19.8	5.3	27.7	58.2	3.5	9.0	12.0
	NON-LEGUME	1.3	13.7	13.9	2.8	3.0	11.7	10.3	26.2	39.8
	GRASS	5.1	17.6	13.5	1.4	4.5	4.2	2.0	6.4	5.8
	TOTAL	10.2	41.4	47.2	9.5	35.2	74.1	15.8	41.6	57.6

Table 3. Relative frequency over time of understory plant groups in aspen stands subject to different trampling intensities.

		STAND								
		ASPEN FERTILIZED			ASPEN NATURAL			ASPEN THINNED		
TRAMPLING INTENSITY		HEAVY	LIGHT	CONTROL	HEAVY	LIGHT	CONTROL	HEAVY	LIGHT	CONTROL
DATE	VEGETATION									
5/28/80	LEGUME	0.0	0.0	0.0	9.3	20.8	27.8	5.6	0.0	0.0
	NON-LEGUME	11.1	1.9	0.0	0.0	0.0	0.0	16.7	19.8	13.9
	GRASS	16.7	25.9	27.8	18.5	6.9	0.0	5.6	7.9	13.9
6/24/80	LEGUME	18.2	11.5	14.4	24.8	26.3	25.8	16.9	14.3	7.4
	NON-LEGUME	3.9	8.5	7.2	1.5	0.8	1.6	8.9	10.9	19.0
	GRASS	5.6	7.8	6.2	1.5	0.6	0.3	1.9	2.6	1.3
7/23/80	LEGUME	16.0	10.8	13.6	24.1	25.7	25.1	14.2	9.9	4.9
	NON-LEGUME	3.4	8.0	7.5	3.0	1.1	2.0	10.9	14.2	20.1
	GRASS	8.3	9.0	6.6	0.7	0.9	0.7	2.6	3.7	2.8
8/20/80	LEGUME	9.5	6.8	12.2	15.3	22.8	23.6	7.2	6.3	5.7
	NON-LEGUME	3.8	8.6	8.0	8.3	2.0	3.1	17.3	17.4	20.0
	GRASS	14.5	12.4	7.5	4.2	2.9	1.1	3.2	4.1	2.0

Table 4. Forest floor mean weight (standard error of $\bar{x}$) in g m^{-2} of aspen and spruce-fir stands subject to different trampling intensities. The May and August collections were made before and after the trampling period. * indicates a significant ($p<.05$) difference between dates. n = 10.

STAND	HEAVY		LIGHT		CONTROL	
	MAY	AUG	MAY	AUG	MAY	AUG
FERTILIZED ASPEN	8636 *	4827	8076 *	3030	8629	7014
	(989)	(625)	(1691)	(386)	(1521)	(846)
NATURAL ASPEN	6806	5514	6446	6919	6395 *	9024
	(966)	(491)	(934)	(623)	(384)	(1082)
THINNED ASPEN	4606 *	2768	3874	3888	5428	4001
	(557)	(259)	(350)	(352)	(771)	(373)
SPRUCE-FIR	10450	8791	11290 *	6599	11030	7922
	(1068)	(1220)	(1636)	(1496)	(1473)	(1307)

Table 5. Relative % cover (standard error) of bare ground overtime in aspen stands subject to different trampling intensities.

FERTILIZED ASPEN	HEAVY	LIGHT	CONTROL
5/28/80	1.20 (.66)	0.00	0.60 (.60)
6/23/80	2.3 (1.7)	0.6 (0.4)	2.8 (1.1)
7/23/80	2.2 (.8)	0.8 (0.6)	1.3 (0.8)
8/20/80	3.3 (2.1)	1.4 (0.8)	1.5 (0.7)
NATURAL ASPEN			
5/28/80	0.00	1.40(1.11)	0.00
6/23/80	0.00	1.4 (1.1)	0.00
7/23/80	2.7 (1.1)	2.9 (1.0)	0.00
8/20/80	1.8 (0.9)	2.2 (2.2)	0.00
THINNED ASPEN			
5/28/80	2.20(2.70)	1.20 (.66)	0.00
6/23/80	2.0 (1.5)	0.6 (0.6)	0.00
7/23/80	1.4 (.8)	1.8 (1.1)	0.00
8/20/80	1.7 (0.8)	2.2 (1.0)	0.3 (0.3)

Table 6. Mean weight and nutrient content (g m^{-2}) of the forest floor of aspen and spruce-fir stands subject to different trampling intensities. The May and August collections were made before and after the trampling period. * indicates a significant ($p<.05$) difference between dates. n = 10.

NATURAL ASPEN	HEAVY		LIGHT		CONTROL	
	MAY	AUG	MAY	AUG	MAY	AUG
Weight	6806	5514	6446	6919	6395 *	9024
Ash Free Wt.	4081	3267	4097	4474	4594 *	6433
Ca	135.2	104.6	134.3	149.9	156.1	184.1
Mg	25.2	19.3	21.7	25.1	19.1	25.4
K	19.5	14.8	15.6	20.9	16.8	20.7
N	104.2	90.2	106.9	126.2	122.1 *	170.9
P	7.51	6.25	7.26	8.08	7.85 *	10.96

FERTILIZED ASPEN	HEAVY		LIGHT		CONTROL	
	MAY	AUG	MAY	AUG	MAY	AUG
Weight	8636 *	4827	8076 *	3030	8629	7014
Ash Free Wt.	4316	3258	4786 *	2185	4365	3836
Ca	143.2 *	95.3	130.5 *	62.0	138.0	106.9
Mg	26.6 *	13.8	22.7 *	8.5	25.7	23.4
K	19.6 *	11.3	16.4 *	6.6	18.0	17.6
N	60.7	82.0	84.6	56.7	101.4	98.0
P	4.23	4.61	5.67	3.13	6.59	6.14

THINNED ASPEN	HEAVY		LIGHT		CONTROL	
	MAY	AUG	MAY	AUG	MAY	AUG
Weight	4606 *	2768	3874	3888	5428	4001
Ash Free Wt.	3300	2176	2785	2833	3428	2648
Ca	94.7	71.4	71.1	81.0	112.5	87.6
Mg	11.6	7.5	9.7	10.5	16.6	13.2
K	8.0	5.6	6.9	7.1	11.6	9.1
N	78.3	46.0	53.9	65.0	85.7	72.5
P	5.18	2.90	3.73	4.13	5.78	5.04

SPRUCE-FIR	HEAVY		LIGHT		CONTROL	
	MAY	AUG	MAY	AUG	MAY	AUG
Weight	10450	8791	11290 *	6599	11030	7922
Ash Free Wt.	5661	5443	5477	3855	6181	5152
Ca	93.4	96.3	75.7	52.7	102.0	85.5
Mg	20.1	15.8	20.7	11.8	18.9	13.7
K	19.2	15.6	19.9	12.4	17.6	14.0
N	96.6	99.0	84.4	69.2	94.1	97.1
P	8.24	7.61	7.81	6.31	7.22	7.35

Table 7. Mean (standard error of $\bar{x}$) permeability (ml cm^{-2} mm^{-1}) and bulk density (g m^{-3}) of soils in aspen and spruce-fir stands subject to different trampling intensities. The May and August collections were made before and after the trampling period. * indicates a significant ($p<.05$) difference between dates. n = 10.

PERMEABILITY	HEAVY		LIGHT		CONTROL	
	MAY	AUG	MAY	AUG	MAY	AUG
FERTILIZED ASPEN	4.55 (1.53)	1.58 (0.57)	6.69 (1.85)	4.56 (0.60)	3.17 (0.83)	3.77 (1.31)
NATURAL ASPEN	3.62 (0.75)	1.38 (0.61)	4.68 (0.95)	2.52 (0.67)	4.09 (0.55)	2.68 (0.58)
THINNED ASPEN	1.61 (0.37)	1.16 (0.19)	1.93 (0.27)	1.62 (0.33)	2.12 (0.53)	1.85 (0.43)
SPRUCE-FIR	1.57 (0.37)	0.95 (0.41)	2.95 (1.60)	1.70 (0.99)	2.10 (1.09)	3.32 (1.77)

BULK DENSITY	HEAVY		LIGHT		CONTROL	
	MAY	AUG	MAY	AUG	MAY	AUG
FERTILIZED ASPEN	.337 (.052)	.550 (.038)	.369 (.038)	.559 (.073)	.438 (.044)	.580 (.064)
NATURAL ASPEN	.535 (.039)	.477 (.027)	.501 (.040)	.571 (.039)	.408 (.042)	.357 (.041)
THINNED ASPEN	.491 (.072)	.448 (.044)	.548 (.054)	.685 (.025)	.625 (.053)	.663 (.067)
SPRUCE-FIR	.433 (.101)	.610 (.074)	.550 (.068)	.632 (.040)	.542 (.071)	.654 (.074)

Table 8. Nitrate concentration (μeq ℓ^{-1}) sample volume (ml) from lysimeter collections made in aspen stands on August 2, 1980.

THINNED ASPEN	CONC.	VOL.	CONC.	VOL.	CONC.	VOL.
LYSIMETER	HEAVY		LIGHT		CONTROL	
1A	-	0	-	0	-	0
1B	-	0	-	0	0.0	164
2A	-	0	0.2	44.1	-	0
2B	1.4	64	-	0	2.0	19
3A	0.4	35	16.2	5	-	0
3B	-	0	-	0	0.4	186
4A	2.7	20	-	0	-	0
4B	-	0	0.2	127	5.9	245
5A	55.0	8	1.8	63	-	0
5B	0.6	14	-	0	3.1	78
$\bar{x}$	12.02		4.60		2.28	
n	5		4		5	
S.E.	10.73		3.89		1.06	

NATURAL ASPEN	CONC.	VOL.	CONC.	VOL.	CONC.	VOL.
LYSIMETER	HEAVY		LIGHT		CONTROL	
1A	-	0	-	0	-	0
1B	-	0	20.3	54	-	0
2A	28.8	33	-	0	-	0
2B	57.3	8	0.4	65	-	0
3A	-	0	5.5	9	-	0
3B	43.4	4	-	0	-	0
4A	1.6	2	9.0	16	-	0
4B	-	0	-	0	-	0
5A	-	0	4.7	85	-	0
5B	-	0	0.2	82	-	0
$\bar{x}$	32.78		6.68			
n	4		6			
S.E.	11.91		3.04			

FERTILIZED ASPEN	CONC.	VOL.	CONC.	VOL.	CONC.	VOL.
LYSIMETER	HEAVY		LIGHT		CONTROL	
1A	44	12	160.5	120	-	0
1B	-	0	-	0	4.1	3
2A	1331	31	28.6	58	36.4	172
2B	-	0	-	0	36.6	126
3A	91.8	59	-	0	1.2	65
3B	2.5	65	-	0	32.3	53
4A	57.1	14	245	11	517	42
4B	113.3	113	-	0	1227	42
5A	-	0	-	0	311	17
5B	102.5	51	3.1	62	-	0
$\bar{x}$	248.89		109.30		270.70	
n	7		4		8	
S.E.	180.64		56.88		151.52	

FIGURE LEGEND

Fig. 1. Design of the 10m x 10m plots and $1/2m^2$ subplots for each forest stand. Trampling intensities were control (0), light (3 walking passes/week) and heavy (18 walking passes/week).

Fig. 2. Aspen understory biomass ($g\ m^{-2}$) after application of different trampling intensities. Different management treatments markedly influenced understory plant composition.

Fig. 3. Changes in % relative coverage of all aspen understory plant groups (legumes, grasses, non-legumes) as influenced by trampling intensity and management treatment.

Fig. 4. Changes in % relative coverage of all aspen understory plant groups (legumes, grasses, non-legumes) as influenced by trampling intensity and management treatment.

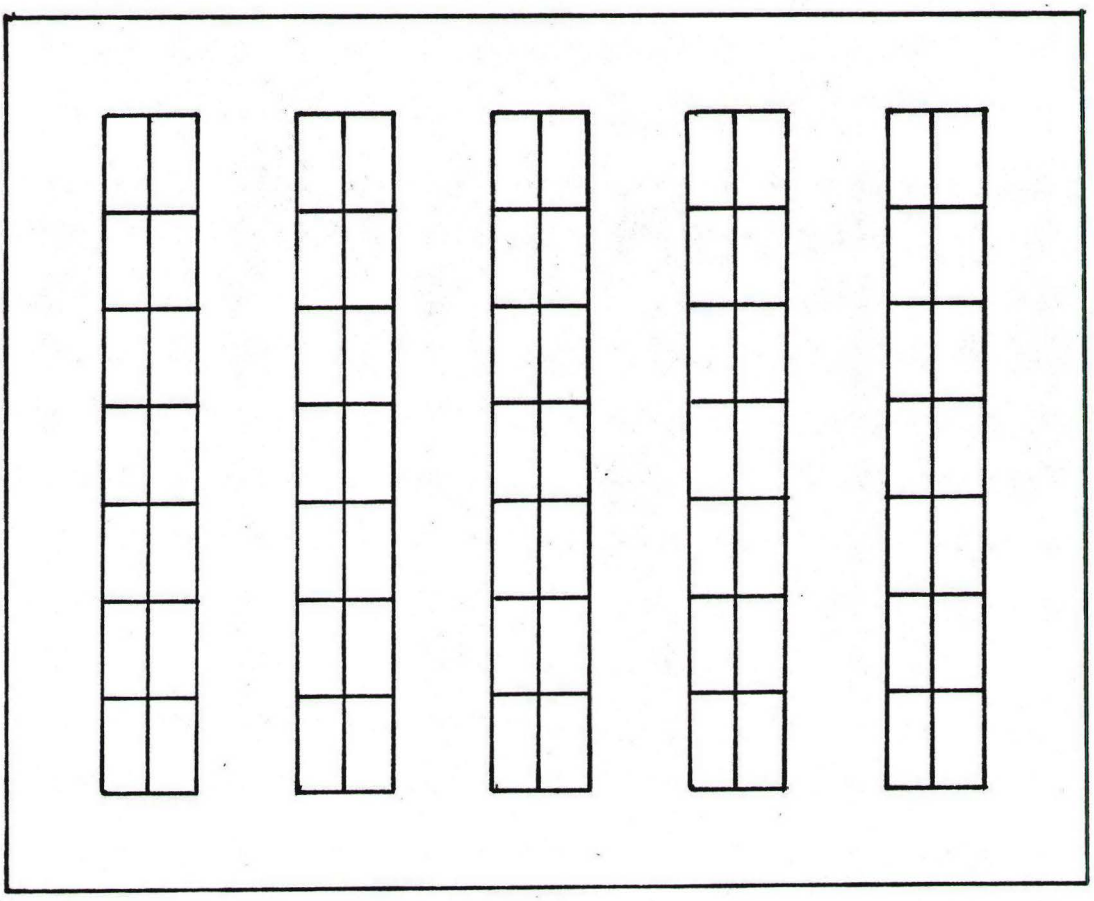
Fig. 5. Nitrate-N concentrations ($\mu eq\ \ell^{-1}$) in the litter of the natural aspen stand under the influence of different trampling intensities.

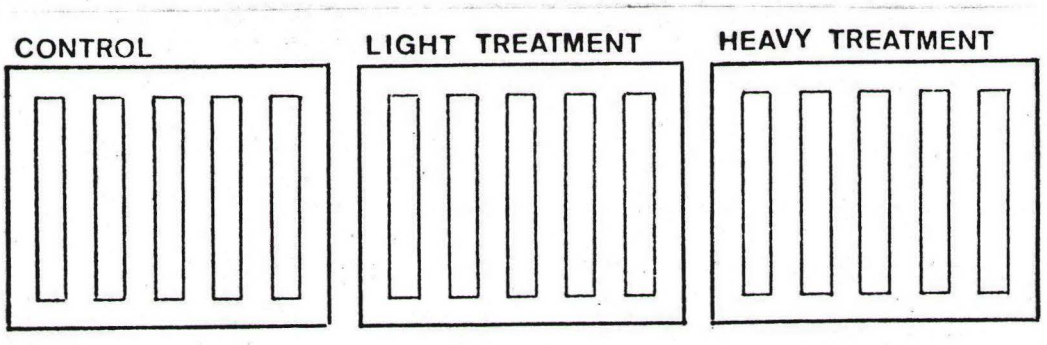
Fig. 6. Nitrate-N concentrations ($\mu eq\ \ell^{-1}$) in the litter of the fertilized aspen stand under the influence of different trampling intensities.

Fig. 7. Nitrate-N concentrations ($\mu eq\ \ell^{-1}$) in the litter of the thinned aspen stand under the influence of different trampling intensities.

Fig. 8. Nitrate-N concentrations ($\mu eq\ \ell^{-1}$) in the top 10 cm of soil of the thinned aspen stand under the influence of different trampling intensities.

Figure 1





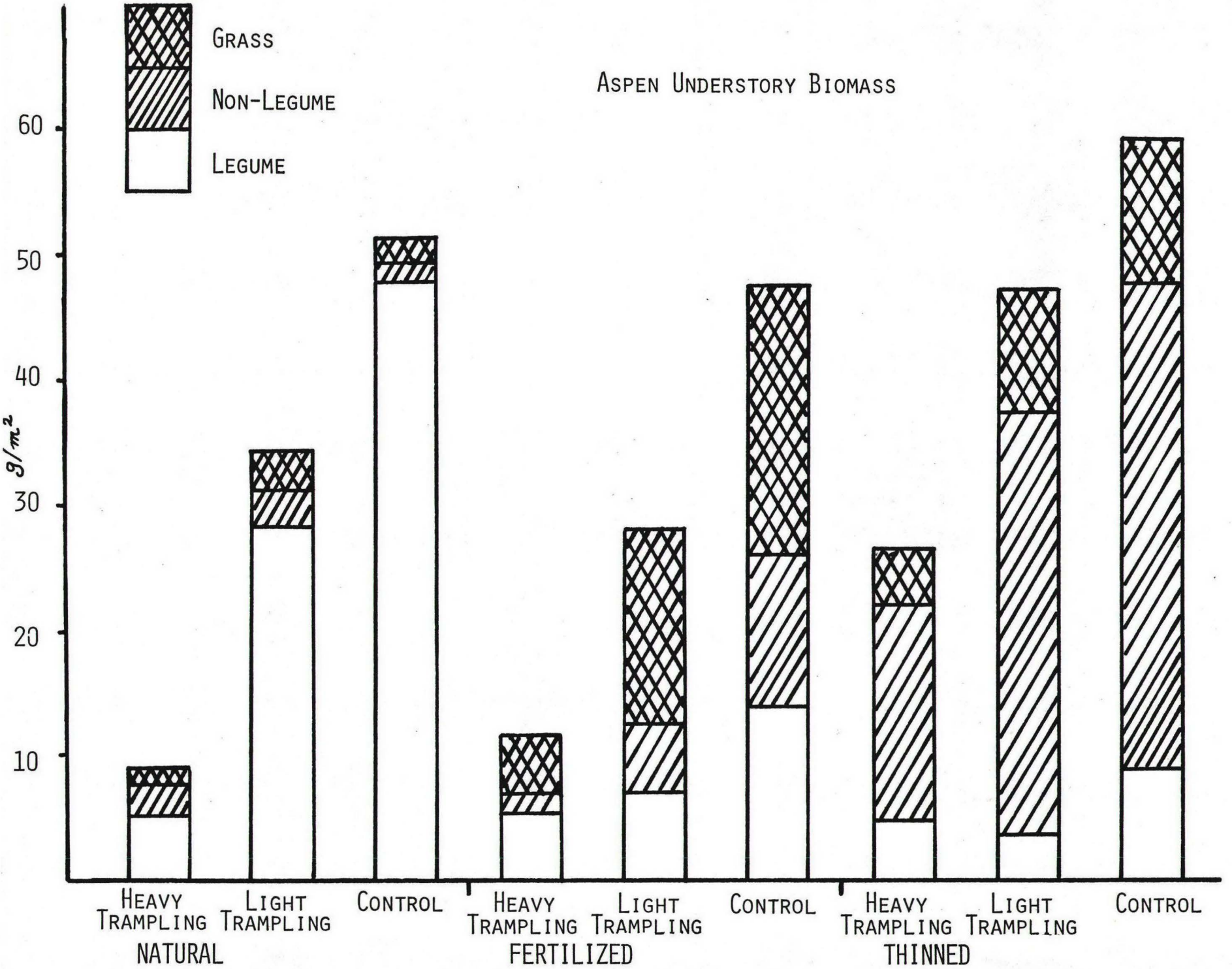

Aspen Understory Biomass
Grass
Non-Legume
Legume
60
50
40
30
20
10
g/m²
Heavy Trampling
Light Trampling
Control
Heavy Trampling
Light Trampling
Control
Heavy Trampling
Light Trampling
Control
Natural
Fertilized
Thinned

Figure 2

FIGURE 3

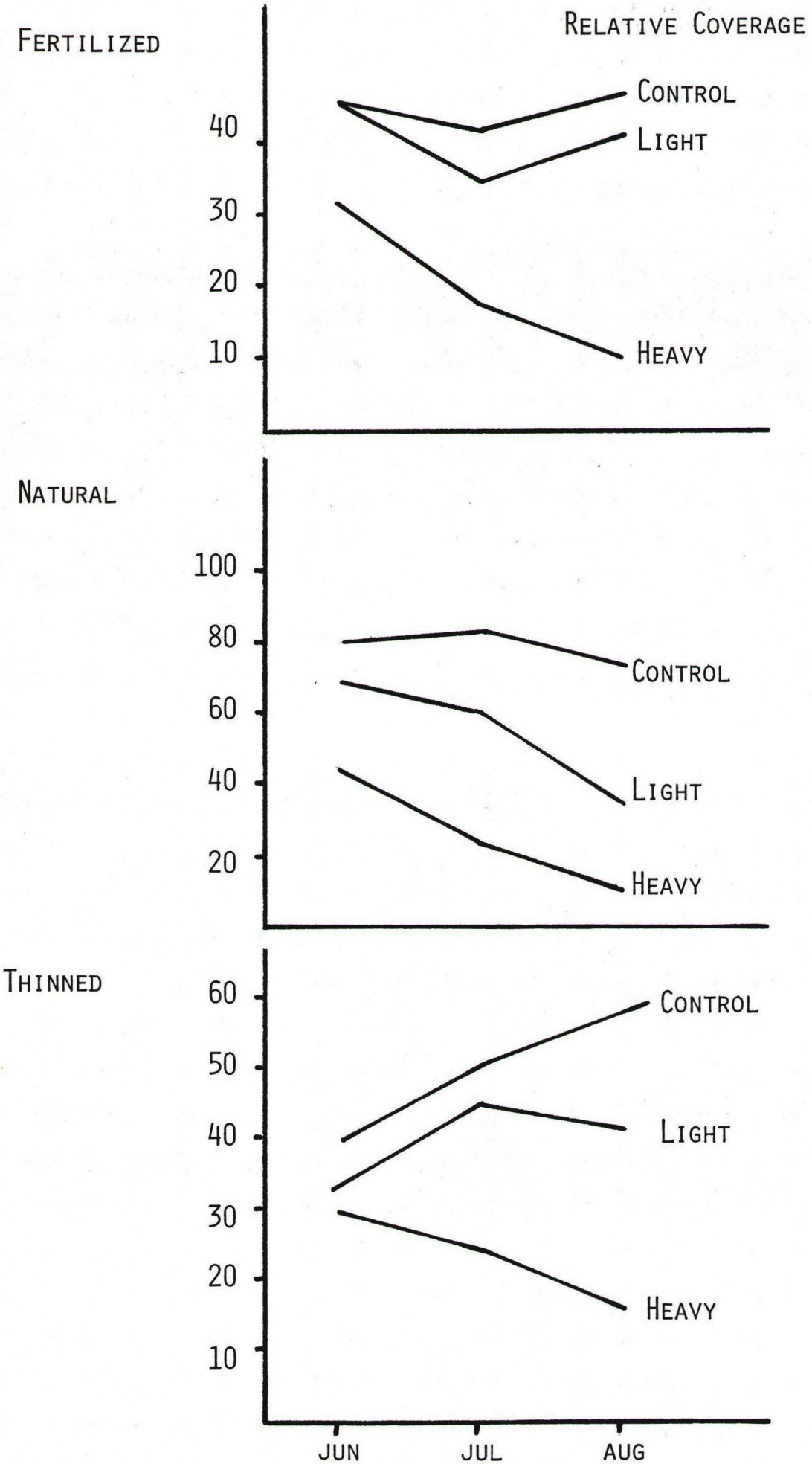
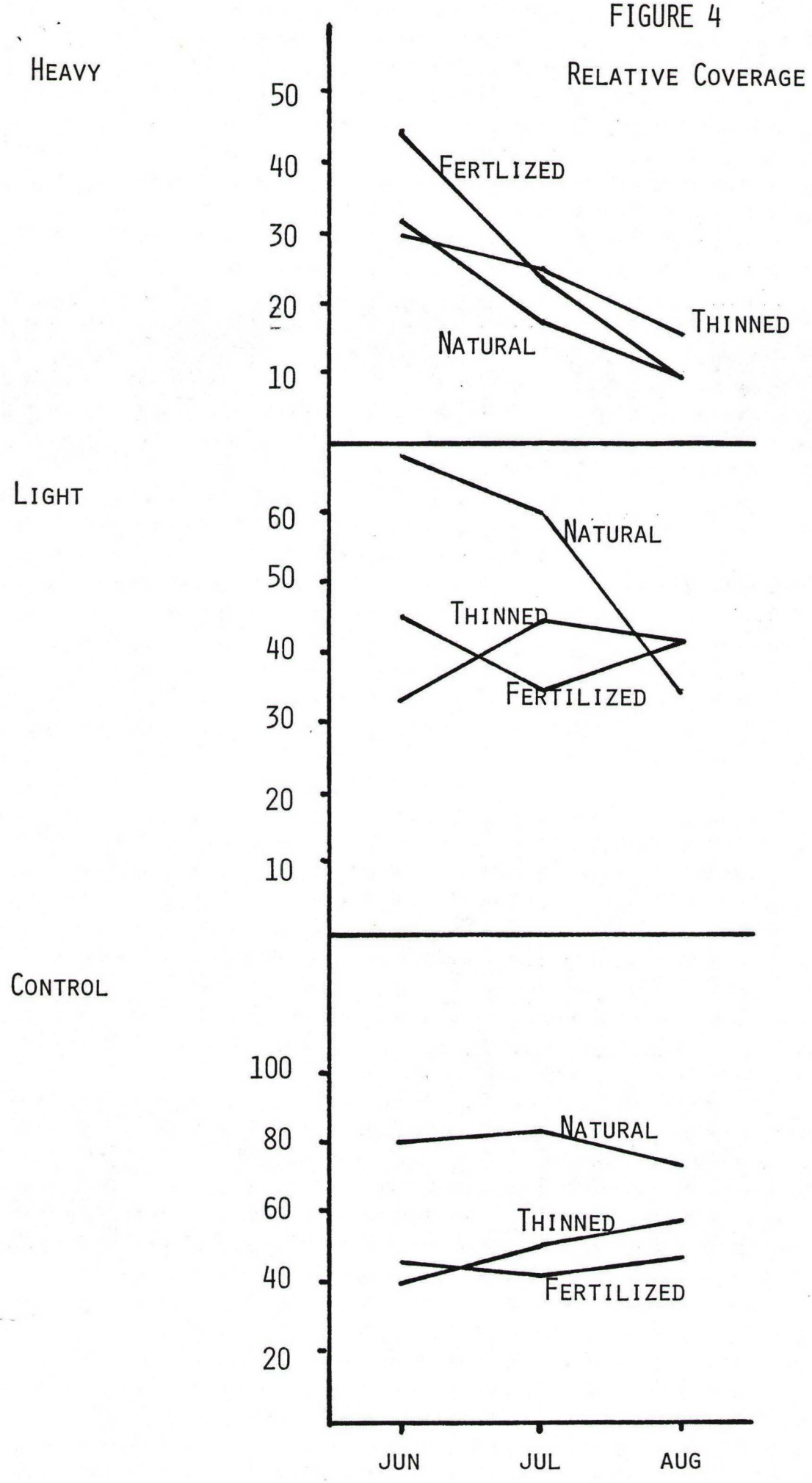

RELATIVE COVERAGE
FERTILIZED
40
30
20
10
CONTROL
LIGHT
HEAVY
NATURAL
100
80
60
40
20
CONTROL
LIGHT
HEAVY
THINNED
60
50
40
30
20
10
CONTROL
LIGHT
HEAVY
JUN
JUL
AUG

FIGURE 4


HEAVY
RELATIVE COVERAGE
50
40
30
20
10
FERTLIZED
THINNED
NATURAL
LIGHT
60
50
40
30
20
10
NATURAL
THINNED
FERTILIZED
CONTROL
100
80
60
40
20
NATURAL
THINNED
FERTILIZED
JUN
JUL
AUG

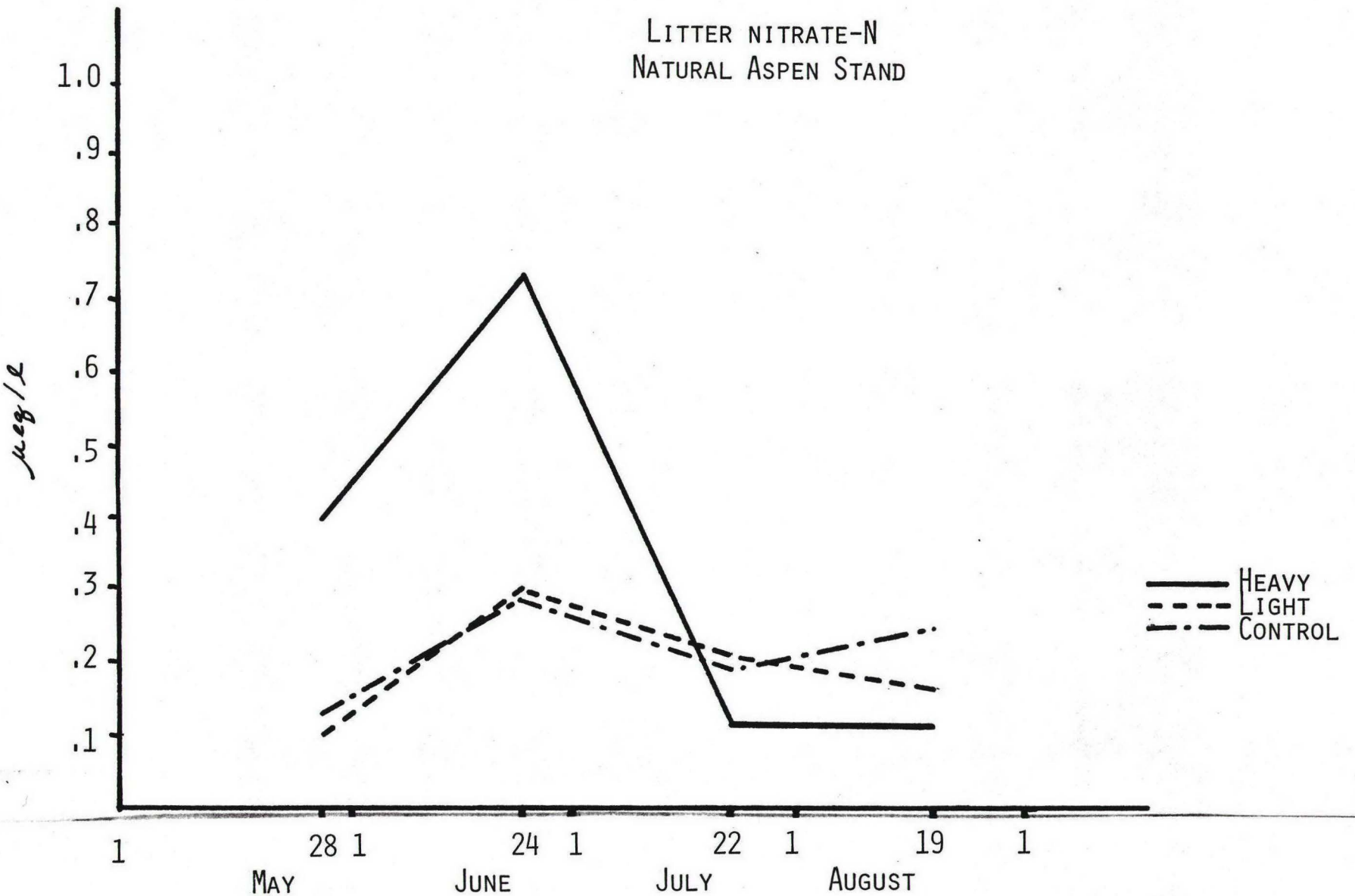

LITTER NITRATE-N
NATURAL ASPEN STAND
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
mg/l
HEAVY
LIGHT
CONTROL
1
28
1
24
1
22
1
19
1
MAY
JUNE
JULY
AUGUST

FIGURE 5

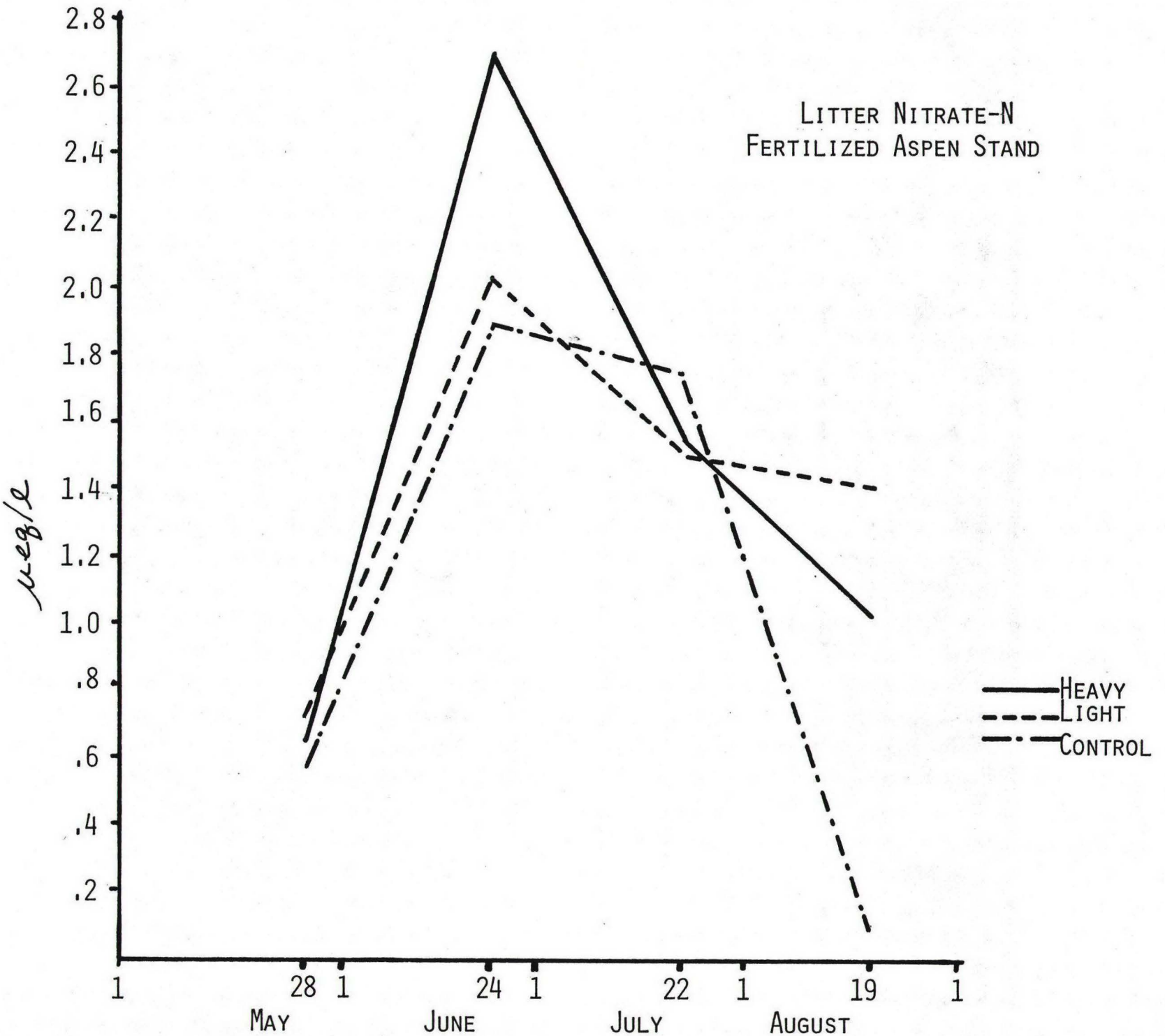

LITTER NITRATE-N
FERTILIZED ASPEN STAND
meq/l
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
1
28
1
24
1
22
1
19
1
MAY
JUNE
JULY
AUGUST
HEAVY
LIGHT
CONTROL

FIGURE 6

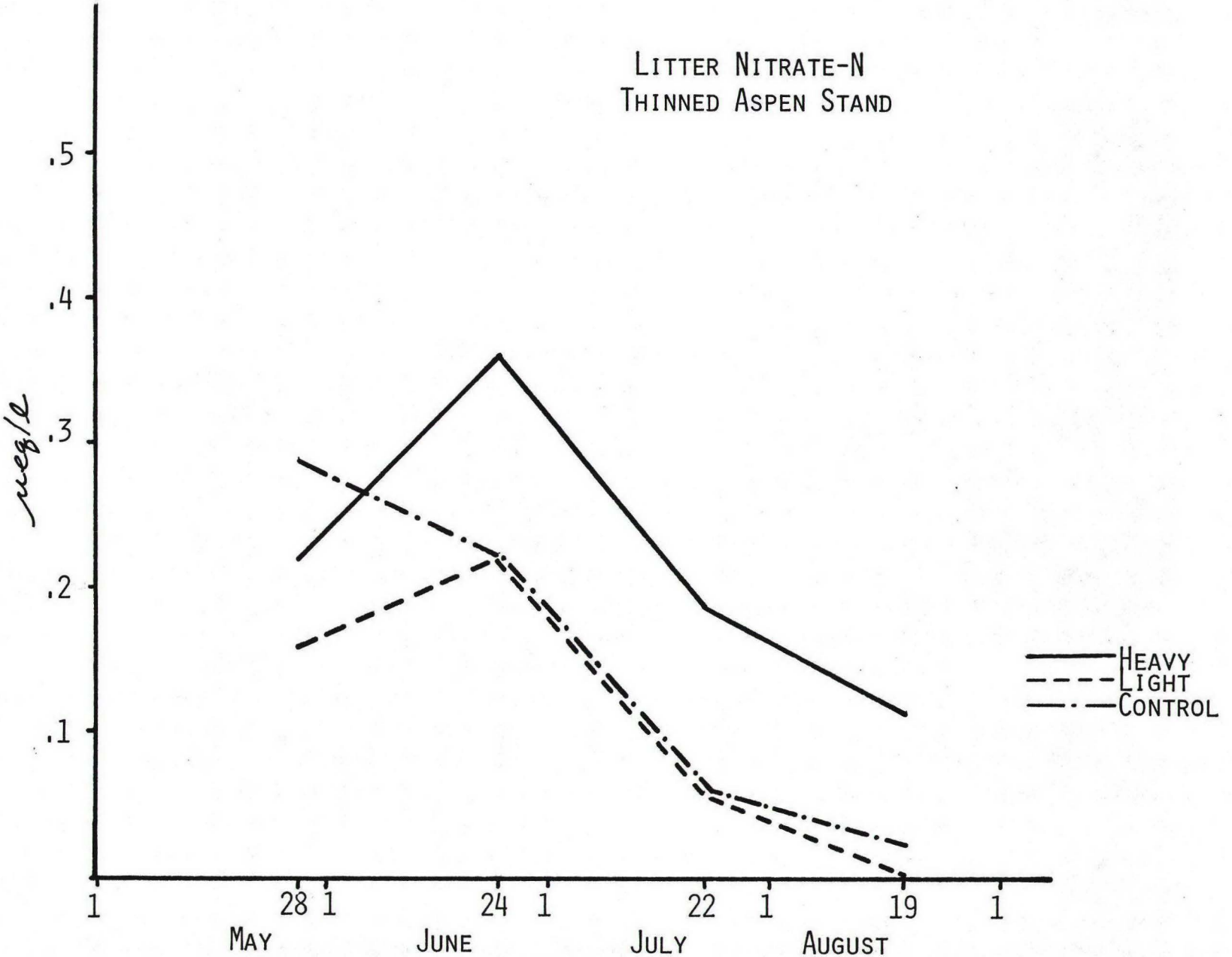

LITTER NITRATE-N
THINNED ASPEN STAND
.5
.4
.3
.2
.1
mg/l
1
28
1
24
1
22
1
19
1
MAY
JUNE
JULY
AUGUST
HEAVY
LIGHT
CONTROL

FIGURE 7

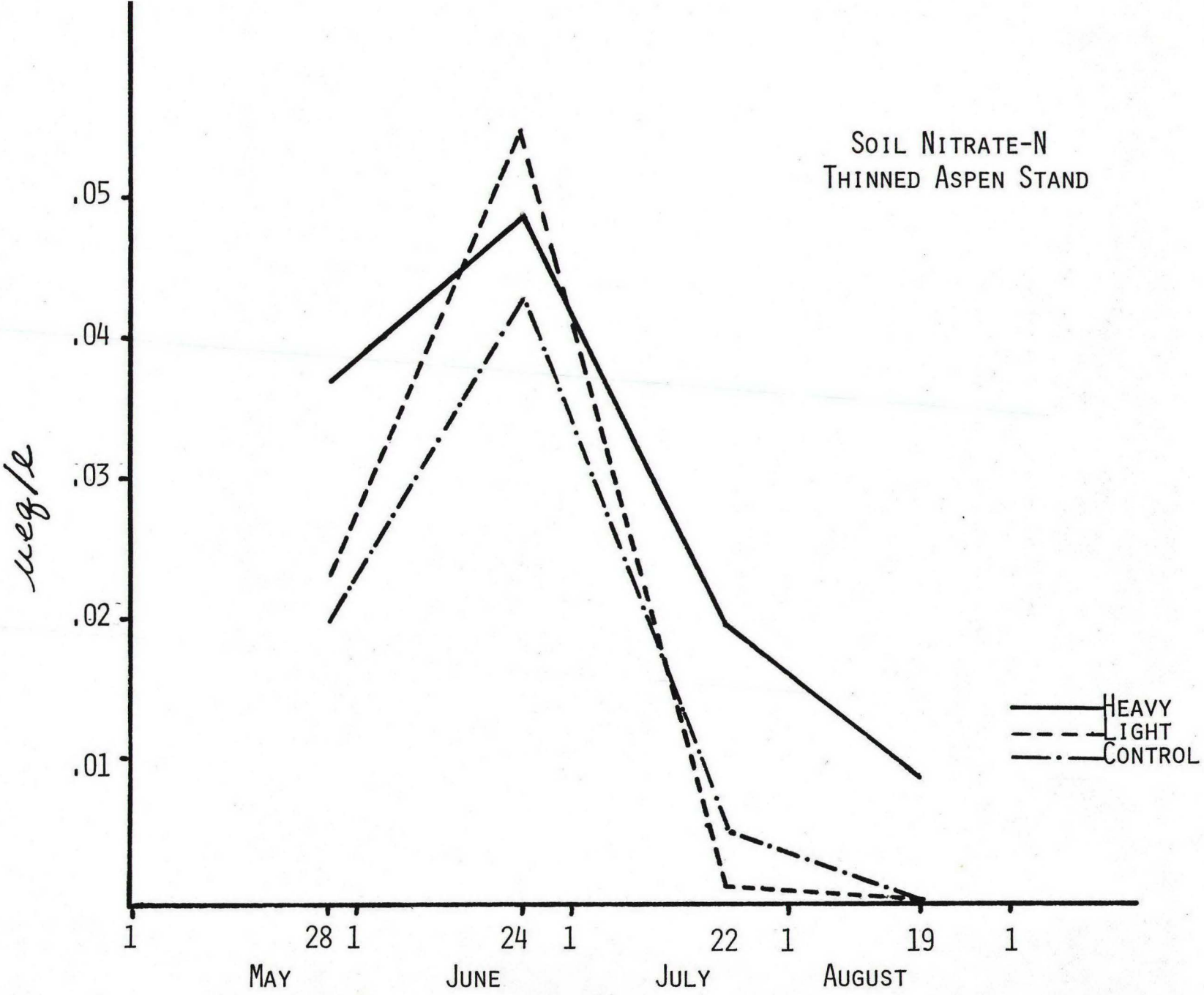

SOIL NITRATE-N
THINNED ASPEN STAND
.05
.04
.03
.02
.01
ug/g
1
28
1
24
1
22
1
19
1
MAY
JUNE
JULY
AUGUST
HEAVY
LIGHT
CONTROL

FIGURE 8